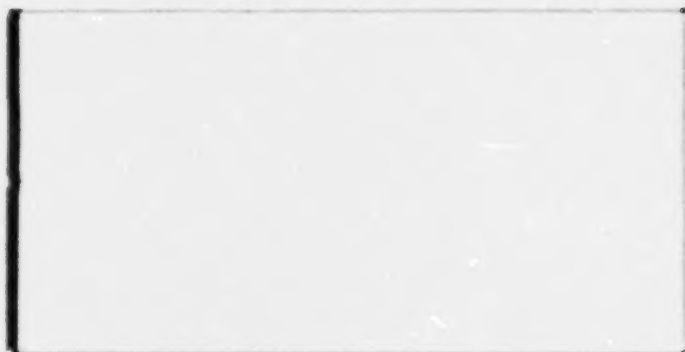




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**CORROSION AND THERMAL PLANT SECTION
1983 REVIEW AND 1984 PROGRAMS**

Report 84-22-K

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ABSTRACT

The projects and achievements of the Corrosion and Thermal Plant Section in 1983 are reviewed. Proposed projects and objectives for 1984 are described in outline and an overview of the changes in direction of the work of the section is presented.

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To Mr. F.J. Kee
Director of Research

CORROSION AND THERMAL PLANT SECTION 1983 REVIEW AND 1984 PROGRAMS

INTRODUCTION

Before reviewing the major accomplishments of the Corrosion and Thermal Plant Section in 1983, the organization of the section will be outlined. Although the section goals and functions as listed below did not alter, staff changes and new program initiatives required some reorganization of resources. Again most of the work of the section fell into three major program areas; Nuclear Generation, Nuclear Waste Disposal and Thermal Generation. This is expected to continue in 1984 and, following the 1983 review, work packages to be completed this year will be summarized. Finally, a prediction as to the direction of the section's activities in the medium and longer terms will be presented.

SECTION GOALS AND FUNCTIONS

Goals

The goals of the section may be summarized as follows:

- to provide a resource of specialized test facilities and advanced knowledge in various aspects of materials science including metal degradation by high temperature deformation and fracture, corrosion and metal/hydrogen isotope interactions
- to carry out pure and applied research in these areas together with supplying consultative, investigative and testing services to other units of the Corporation

Functions

The section is organized to ensure that its expertise and resources may be used to:

- assist in design of processes and systems to maximize efficiency of electricity production and transmission
- help maintain and/or improve process and system reliability
- solve problems occurring in the power system
- forecast and plan for future demands for service particularly in the area of lateral business opportunities

STAFF AND MAJOR AREAS OF ACTIVITY

Late in 1982, P.F. Timmins, an engineer in the Heavy Water Plant Corrosion Unit (#2), resigned from the Corporation. In September, 1983, G. Kubota, a technician in the same unit, took early retirement. Coincidentally, the amount of research required in support of the heavy water plants reduced significantly. Therefore, the corrosion research work which remained in this area was transferred to the Power Plant Corrosion Unit (#1) and the responsibility for failure analysis of heavy water plant components was assumed by the Metallurgy Section. The technologist, B.L. Fishbein, remaining in Unit #2 was assigned, therefore, to Unit #1 to help with the increased workload, and also to assist with the large amount of research being undertaken with respect to tritium technology. Furthermore, as a result of obtaining a contract to build the TRF's immobilization system, Mr. A.G. Heics, engineer, was hired and Mr. G. Till was obtained on loan from the Chemical Research Department for at least the duration of the contract. In recent months the section was also fortunate to acquire the services of a visiting professor, Dr. L.G. Walker of the Ryerson Polytechnical Institute, and those of Mr. N.P. Kherani on a temporary basis. The current organization of the section is as follows, also noting that the unit head from the Thermal Plant Metallurgy resigned from the Corporation in order to return to the U.K. in November 1983.

Power Plant Corrosion (Unit #1)

Unit Head - Corrosion: Dr. P. Mayer

Engineers: Dr. A.V. Manolescu
 Mr. J.O. Noga
 Dr. W.T. Shmayda
 Mr. A.G. Heics
 Mr. N.P. Kherani

Visiting Professor: Dr. L.G. Walker

Technologists: Mr. A.C. Headon
 Mr. K.D. Geiger
 Mr. B.L. Fishbein

Technicians: Mr. M.J. Dudycz
Mr. J.W. Mummenhoff
Mr. E.M. Rasile
Mr. G. Till

- Carry out pure and applied research into corrosion behaviour of metallic construction materials used in the generation and transmission of power and in the production of heavy water in order to solve existing and anticipate future problems.
- Develop and test materials processes and measures for protection of structures and equipment against metal wastage due to corrosion.
- Provide failure analysis service and consultation on corrosion related problems to the Corporation.
- Investigate metal/hydrogen isotope interactions in support of the Tritium Removal System (TRS).
- Provide a resource to undertake research and to act as a consultant to the Canadian Fusion Fuels Technology Project (CFFTP).

Nuclear Steam Generator and Nuclear Waste Container Corrosion (Unit #3)

Engineers: Mr. P.J. King
Dr. K.W. Lam

Technicians: Mr. S.W. Borda
Mr. L. Chee
Mr. L. Grant

- Develop and evaluate electrochemical corrosion monitoring techniques for corrosion research.
- Carry out pure and applied research into the corrosion properties of possible container materials for the underground disposal of irradiated nuclear fuel.
- Evaluate and research into electrochemical systems for the generation, storage and utilization of electricity.
- Research into the corrosion of nuclear steam generator tubing and support structure alloys under operating and fault-water conditions.

Thermal Plant Metallurgy (Unit #4)

Unit Head: Vacant

Engineers: Mr. W.K. Lee
Dr. J.D. Parker

Attached Ph.D. Student: Mr. S.J. Thorpe

Technologist: Mr. Z. Grozdanovski

Technicians: Mr. R.E. Irwin
Mr. D.A. Oad

- Carry out pure and applied research into deformation and fracture of metals at elevated temperature.
- Test materials and components under simulated thermal plant conditions.
- Determine creep, low-cycle fatigue and crack growth properties of thermal plant materials.
- Investigate and develop methods for residual creep life prediction of plant components.
- Carry out failure investigations of plant components.

MAJOR CLIENT GROUPS

D&D - Design & Development Division
CFFTP - Canadian Fusion Fuels Technology Project
GPD - Generation Projects Division
NGD - Nuclear Generation Division
TGD - Thermal Generation Division
CEA - Canadian Electrical Association
LNL - London Nuclear Ltd
ECUD - Energy Conservation and Utilization Division

1983 RESEARCH PROGRAMS

PROGRAM AREA - NUCLEAR GENERATION

(a) Tritium Removal Facility (TRF)

- Tritium Immobilization Process Development

Major components to be used in the Darlington Tritium Immobilization System (TIS) were tested. These included valves, oil-free pumps, fittings and instrumentation. The results and experiences gained from the testing showed adequate performance for the TIS design requirements. A full scale loop is nearing completion which will provide supporting design optimization data. This loop will also be used for testing of a prototype Immobilized Tritium Container (ITC). (Unit 1; D&D)

- Darlington Tritium Immobilization System Construction

The Darlington TIS will be constructed by OHRD as a result of the experience and knowledge gained through previous developmental work. Work on this project began in July, 1984 with construction scheduled to begin in the first quarter of 1984. The work completed to date has included preparation of design specifications, identification of regulatory requirements, preparation of quality control procedures, detailed design and review of operating requirements. (Unit 1; GPD)

(b) Fusion/Tritium Technology Related

- Development of Uranium Getter Beds

Uranium getter beds may be used in primary delivery systems for fusion reactors and also as temporary storage and purification beds in Ontario Hydro's Tritium Application Program. The performance characteristics of uranium beds were investigated in two interrelated experimental programs. An assessment of factors that influence hydrogen loading rates was carried out on an OHRD designed and constructed 15 g bed. The impact of scaling up to 6 kg and the importance of double containment were studied on the uranium bed designed and built by the Los Alamos Scientific Laboratory. On the basis of this data base, a 3 kg bed is being designed and constructed. This bed will use double containment. The primary stainless steel container will house two copper cups each of which will contain uranium metal in separate compartments. The stainless steel secondary container will incorporate the bed heaters and thermal shielding. Contact between the primary and secondary containers will be minimized to reduce heat losses during bed regeneration cycles. The annular region will be evacuated. Bed construction is expected to be complete early in 1984. Hydriding tests are expected to be carried out during mid 1984. (Unit 1; D&D)

- Fusion Exhaust Fuel Cleanup

The experimental design and ordering of equipment was completed with assembly of the apparatus started in late 1983. Preliminary evaluation of gettering capabilities of candidate materials for the removal of active gas impurities has been encouraging. The only apparent limitation is the high temperature required for operation of most getter materials. This high temperature is necessary in order to prevent significant uptake of hydrogen isotopes by the getter. (Unit 1, CFFTP)

- Compact Torus Study

A review of fusion reactor concepts that are alternatives to the mainline tokamak/mirror/stellarator approach was carried out. The objective of this work was, in the first instance, to establish which if any of these devices were at or near the DT burning phase, open lines of communications with the responsible researchers and identify any potential opportunities for CFFTP. Phase one of this work has been completed. A follow up phase will be implemented after an interim report is issued. (Unit 1, CFFTP)

- Atomic Hydrogen Permeation Studies

A research program has been implemented to look at the permeability of typical first wall and limiter materials that could be used in fusion reactors. This program is a collaborative effort involving Ontario Hydro Research Division, University of Toronto and Nuclear Research Establishment (KFA) in Julich, West Germany. The objective of this work is to use composite materials to enhance hydrogen permeation through the reactor walls and in this way help control the neutron density within the plasma core during the critical ramp down phase of a fusion burn. The second application of this work will center on the use of asymmetric permeation membranes within the throat of limiter blades to selectively remove a fraction of the hydrogen fuels from the reactor exhaust. (Unit 1, CFFTP)

- Laboratory Facilities

The need for a tritium laboratory at Research Division has become increasingly more evident during 1983. A variety of corporate documents have elucidated this need. Efforts to design a tritium laboratory began. A laboratory site attached to the north wall of the existing RML has been proposed. A conceptual layout for purposes of allowing Architectural Services to estimate the cost of a suitable building has been completed. A financial evaluation has also been submitted. Currently, efforts are underway to design tritium supply and delivery systems. The design concept has focussed on modularity to accommodate as many tritium related experiments as possible to meet the Research Division requirements. The tritium delivery system will be housed in a

independent glovebox remote from all experimental stations. An automated delivery system is visualized to minimize operator error. Each experimental station will be a free standing work bench complete with its own power and inert atmosphere supply. A plexi-glass cover over the work bench will provide the needed secondary containment. The inert gas will be stacked or scrubbed free of tritium and recirculated. Recirculation will only be local to a particular work bench to prevent cross contamination between benches.

Modifications to the hydrogen sulfide laboratory have also been proposed to expand our capabilities to handle hydrogen. Architectural Services have obtained Ministry of Labour approval to proceed with the lab expansion. Tenders have been requested for the construction phase. Occupancy at the end of January 1984 is anticipated. In addition to some limited low level hydrogen sulfide work, this laboratory will, in the first two years house the 3 kg uranium bed test stand, a loop to study the kinetics of hydrogen isotope transfer between titanium and uranium beds, and two hydrogen permeation related experiments.
(Unit 1; CFFTP, NGD and D&D)

(c) Heavy Water Plant

- Durability Testing of Protective Scales in Heavy Water

The effect of process additives and contaminants, at Bruce Heavy Water Plant, on the morphology and durability of the protective scales which form on internal surfaces was investigated. The test program in both static and dynamic environment was completed. The results obtained indicate that the antifoam additive and seal oil contaminations of the water hydrogen sulfide process solution cause partial loss of the scale protectiveness. (Unit 1; NGD)

- Corrosion Inspection at the Mothballed BHWP-D

A corrosion inspection at the mothballed BHWP-D of E7, E8, Vacuum Degassing Unit, Large Bore Fabrication Shop, Small Bore Fabrication Shop and Lay Down Area was conducted to examine the protected structures for corrosion. A report was prepared describing the rate of corrosion of the structures and noting areas where corrective action was needed to reduce excessive corrosion.
(Unit 1; NGD)

(d) CANDU Primary Side

- Corrosion of Pickering G16 and J15 Fuel Channels

Oxide scales which were observed on internal surfaces of pressure tubes removed from Pickering NGS U2 were substantially thicker than previously anticipated. Therefore, an attempt has been made to calculate new estimates based on a model incorporating the most

recent data available in the literature. The calculated oxide thickness profiles along the fuel channel are in good agreement with the observed values. (Unit 1; D&D)

- Crevice Corrosion

There are two approaches to eliminate or reduce the accelerated corrosion of pressure tubes due to accumulation of lithium hydroxide alkalizer under fuel bundle bearing pads: bearing pad redesign and chemistry change. The most viable option in the second approach is the use of inhibitors, in minute quantities, to mitigate the corrosion. The classes of inhibitors suitable for this application are:

- neutralizing salts
- water dissociation poisons
- hydrogen ion scavengers
- hydrogen recombination catalysts

Based on encouraging results of limited tests in static autoclaves, a proposal to develop an inhibitor system for use in CANDU power reactors was submitted to Nuclear Generation.

In spite of these results, no further work was carried out. The fuel bundle bearing redesign was given first priority. It is expected that the bearing redesign approach will be successful and as a consequence no alternative solution to the problem is required, although crevice corrosion simulation work using a refreshed system is continuing in order to be prepared for future evaluation studies. (Unit 1; NGD)

- Delayed Hydride Cracking in PHT Environment

The main objective of this program is to determine if there is any significant effect of Primary Heat Transport environment on the crack growth behaviour of Zr-2.5% Nb pressure tube material. The elastic compliance method to calculate Stress Intensity Factor (K) and the AC potential drop instrument to measure crack length were both successfully applied to Compact Tension Specimens (CTS) with 50 ppm hydrogen. Baseline tests in air on self-loaded CTS at 250°C produced crack growth rates and K threshold values similar to published data. Preliminary work on crack growth measurement in an autoclave was completed. Improvement in electrical isolation for the AC potential drop instrument was considered the major problem to be solved. (Unit 1; NGD)

- Effect of Oxide Formation in Cracks on Delayed Hydrogen Cracking of Fuel Channels

The oxide growth inside tight cracks such as those caused by over-rolling of fuel channel rolled joints is 6 to 8 times higher than on ID of the pressure tubes. This accelerated corrosion, induced

by concentration of lithium hydroxide alkalizer, can cause crack propagation. Preliminary tests indicated two possible effects:

- oxide jacking during operation can cause slow crack propagation due to continuous accelerated formation of the oxide
- wedging action of the oxide during shutdown causes radial-axial hydride formation at the crack tip which cracks immediately (if the oxide is thick) or upon subsequent pressurization on start up.

Of particular concern is the growth of short sharp cracks (less than 0.2 mm deep) in the area of rolled joints when hydrogen concentration in the pressure tube exceeds the terminal solid solubility at the operating temperature.

A program to investigate this phenomenon has been initiated. The design, fabrication and calibration of four-point bent fixtures required for the autoclave test were carried out. Also, the preparation of pre-cracked specimens containing, as received and 80 ppm of dissolved hydrogen, was completed. The autoclave tests will commence early in 1984. (Unit 1; NGD)

- Decontaminability of Primary Heat Transport System

As a part of the effort to investigate the relationship between decontaminability and structural and compositional characteristics of magnetite oxide which forms on internal surfaces of PHTS, corrosion coupons from operating reactors were analyzed in detail. The structural studies of the oxides include SEM, EDXA, Auger Electron Microscopy (AEM) and Scanning-Transmission Electron Microscopy (STEM). The latter technique, a novel application of electron optics to study oxide composition and structure, is currently under intensive development. The use of this technique improved significantly our ability to analyze corrosion scales. The technique offers at least 100 times better resolution than SEM and ability to identify compounds in addition to compositional analysis.

The rate of the dissolution process during the decontamination process depends on the physiochemical state of the indigenous oxide, which is governed by the PHT environment and the substrate material characteristics. A program to investigate metallurgical effects on the magnetite decontaminability was initiated in cooperation with the Chemical Research Department. (Unit 1; NGD)

- Corrosion by Decontamination Fluids of Fuelling Machine Components

A program to determine the corrosivity of a proposed decontamination solvent, persulphate reagent, and the corrosivity of a second oxide dissolving solution on the numerous metals used in the

fuelling machines was carried out. Galvanic, crevice, stress corrosion cracking and general corrosion studies were conducted. (Unit 1; NGD)

- Erosion-Corrosion of Feeder Tubes

Physiochemical analysis of the primary heat transport circuit revealed that the inlet feeder tubes of CANDU reactors may be prone to an accelerated metal attack by the circulating coolant. Although NDT inspection did not show any tube thinning at this location, it is believed that combined effect of corrosion and coolant flow can cause enhanced metal loss after an initial period of low loss. A program at NPD to investigate the kinetics of this phenomenon was proposed. (Unit 1; NGD)

- Stress Corrosion Cracking of Austenitic Alloys in High Temperature Waters

A program was initiated to test the possible effects of decontamination on materials when a unit is returned to service. Test apparatus, involving four 0.5 L autoclave vessels in a refreshed high temperature water system, was set up for Constant Extension Rate Testing (CERT) of austenitic alloys in simulated reactor water environments. Tests have been performed on sensitized and non-sensitized 304 stainless steel at 287°C in high purity water containing 200 ppb oxygen, and at strain rates from 10^{-7} to 10^{-6} sec⁻¹. No cracking has occurred in non-sensitized samples, while cracking and fracture has occurred in sensitized materials. (Unit 3; LNL)

- Crevice/Pitting Corrosion of Incoloy 800 Moderator Heat Exchanger Tubing

The aim of this project is to investigate the crevice corrosion of 1800 moderator tubing and evaluate possible solutions to the problem. The work involves three main parts: electrochemical studies, (laboratory) immersion testing, and (in-plant) model heat exchanger immersion testing. Work was performed in all three parts in 1983. A number of cyclic polarization tests were performed on Incoloy 800 in Lake Ontario (Pickering Site) and Lake Huron (Bruce Site) waters, and in several specific solutions. The results indicate that 1800 is much more resistant to attack in Lake Huron water than in Lake Ontario water, in the absence of clay/silt deposits. At ambient temperature, 1800 is very resistant to damage in Lake Ontario water, but at slightly elevated temperature (>40°C) crevice attack is more readily supported. The presence of a clay deposit increases susceptibility at lower temperatures, so that crevice attack can be supported at 30°C. This data suggests that chemical cleaning of moderator heat exchangers may be beneficial in reducing the likelihood and extent of tubing crevice corrosion.

Immersion testing in Lake Ontario and Lake Huron waters was started late in the year; no results are available yet from this part of the work.

A model heat exchanger system was designed for use in on-site testing of moderator heat exchanger tubing. The Equipment and Reliability section of CNS undertook detailed design of the heat exchanger vessels. The system comprises three vessels in parallel, with a recirculating loop and 60 kW heater for tube-side water; connection is to be made to a service water system for shell-side water supply. (Unit 3; NGD)

(e) CANDU - Secondary Side

- Steam Generator Corrosion Research

Exposure of Inconel 600 tubing to 260°C water simulating secondary side condition was continued to investigate pitting and crevice corrosion. Static autoclave testing was interrupted early in the year to focus effort on other projects; several exposures to 1000 hours duration were completed before testing was stopped. Quantitative kinetic information is not available from these tests, but it has been observed that in high chloride water (1000 ppm) crevice attack can initiate rapidly.

Testing of unstressed, creviced, Inconel 600 tubing in the re-freshed loop system was carried out intermittently throughout the year. Test environments were high temperature (255°C) deionized water containing from 50 to 200 ppb of oxygen; durations ranged from 200 to 300 hours. As anticipated, no attack of the Inconel 600 tubing was observed under these conditions.

Commissioning of the second phase of the steam generator tubing test loop was greatly extended due to the installation of additional plumbing and electrical facilities. Several Constant Extension Rate Tests (CERT) have been run at high strain rates in air and water (not flowing) at room temperature and 240°C, to provide baseline data. Samples in these tests were pulled to failure.

Samples of steam generator tubing, removed from the U-bend region of Bruce steam generators due to tube failures, were examined for corrosion on the secondary tube surface (OD). No attack could be discerned under deposits on the free tube surface, nor within creviced regions.

A short project to produce intergranular attack of various depths on Inconel 600 steam generator tubing was initiated. Progress was made in defining conditions that would be required to produce controlled attack but the project was postponed due to late delivery of material and lack of manpower.

More testing was planned for 1983 than actually carried out in this area. The amount of testing was reduced primarily due to a shift in effort to work on other projects, ie, the pitting/crevice

corrosion of Incoloy moderator tubing, and the stress corrosion of other austenitic alloys in high temperature waters.
(Unit 3; NGD and D&D)

- Stress Corrosion of Low Pressure Turbine Rotor Disc Steel

The assembly and testing of the apparatus was completed by mid year, after delays due to extra assessment of the safety of the system, and full non-destructive inspection of the pressure vessels. Upon completion, the system of four pressure vessels in series was operated for about 1700 hours. This first test was stopped due to unacceptably high oxygen levels, caused by air inleakage. New specimens were fabricated and the testing re-started at the end of November, after taking steps to rectify the air inleakage problem.

Examination of samples from the first test series indicated neither crack initiation nor growth in condensing steam at temperatures of 180, 150, 120, and 90°C. Some pitting was apparent in creviced regions of crack initiation samples, and all samples underwent general, superficial corrosion.

Crack growth samples in the first test series were fitted with foil or incremental type crack propagation gauges. The coatings applied to protect these gauges from the condensing steam failed, and the gauges de-bonded from the specimen surface. Crack growth specimens in the second series are ungauged. (Unit 3; NGD)

- Electrochemical Technique Development

An electrode assembly for long term corrosion testing at up to 200°C was designed and constructed. The assembly, involving a series of O-rings and couplings, was in continuous use for over three months at 150°C without leak.

A numerical method for the simultaneous determination of corrosion current and anodic and cathodic Tafel constants in the non-Tafel potential region has been developed. A computer program was written and is being tested for its applicability to real systems.
(Unit 3; NGD and D&D)

PROGRAM AREA - NUCLEAR WASTE DISPOSAL

(a) High Level Waste

- Advanced Container Corrosion Studies

Testing of copper for use as a container material for the disposal of irradiated nuclear fuel waste is continuing. Long term exposure of copper in sulphide containing synthetic groundwater-bentonite slurries at 75°C is near completion. Testing at 150°C is in progress.

Apparatus and instruments for testing the effects of radiolysis on copper corrosion were improved and assembled. A suspension device for holding the apparatus was constructed. The system, consisting of corrosion monitoring instruments, temperature controlling devices and a water-tight protective cylinder containing autoclaves is being safety tested. (Unit 3; D&D)

PROGRAM AREA - THERMAL GENERATION

(a) Water/Steam System

- Superheater/Reheater Exfoliation

Exfoliation of scales which form on the internal surface of superheater and reheater tubes leads to severe erosion damage of turbines as the oxide particles contained in the steam are highly erosive. One of the solutions to this problem is the chemical treatment of the steamside scale to facilitate its plastic flow and to block the mass transport through the oxide scale. Development of such a chemical treatment is the objective of this three year program. Funding is being provided by the Canadian Electrical Association. Excellent progress was made in this program with the first two phases accomplished. Several boron containing formulations were identified and thoroughly tested in the laboratory. The best candidate chemical treatments were then used to treat sections of reheater tubes at Lambton TGS for long term testing. (Unit 1; TGD and CEA)

- High Temperature Crack Growth

Improved signal to noise ratio was obtained with the modified AC potential drop instrument for crack growth measurement. The microcomputer based data logger was successfully linked to the servo hydraulic fatigue machine. The system recorded both the fatigue cycle number and the AC potential drop voltages at desired cycle intervals. Calibration tests in air at room temperature and at 625°C produced crack voltage vs crack length curves similar to published results obtained by the DC potential drop method for the Compact Tension Specimen (CTS). The AC technique was superior since it was not affected by the thermal emf generated at any electrical connections.

Due to unforeseen delay in tests on CTS, the test progress on the Centre Cracked specimens (as outlined in 1983 plan) was limited to a signal stability check of the AC potential drop method. An appropriate induction coil was also procured for the high temperature crack growth test. The experiment on crack growth in a boiler tube under simulated two shift condition was not completed due to manpower shortage.

A paper in collaboration with the University of Toronto on the high temperature crack growth behaviour of 2-1/4 Cr-1 Mo steel was accepted for presentation at the ASME Pressure Vessel and Piping Conference. An elastic-plastic Fracture Mechanics Analysis of the available crack growth data in CTS was also carried out. The cyclic J integral parameter was found to be as good as the Stress Intensity Factor (K) parameter.

The σ_{net} parameter was considered to be a poor correlation parameter to describe crack growth in terms of the stress state. The cyclic J integral provided a less pessimistic assessment of the crack growth behaviour and was less conservative than K for the structural analysis. (Unit 4; TGD)

- Thermal Fatigue

The test program was not carried out due to unavailability of test machine time and a change in work priority for the two shift program. The thermal fatigue data was not immediately required for refinement to the stress analysis. However, all necessary equipment has been assembled with the exception of a load coil transformer to improve the efficiency of the induction heater. (Unit 4; TGD and CEA)

- High Temperature Bolting - Rejuvenation

Due to manpower shortage, not much progress was achieved by Westinghouse on the CEA program. Additional tests were performed on serviced bolts supplied by Nova Scotia Power. No appreciable change in either physical properties or microstructures was observed. The project was redirected to investigate the effect of reheat treatment/Hot Isostatic Pressing on artificially damaged bolt material. Creep aging to the tertiary stage with up to 10% elongation was carried out on new material to simulate service damage. (Unit 4; TGD)

- Corrosion Fatigue - Crack Initiation

The static autoclave vessel was received and registered with the Ministry of Consumer and Commercial Relation (MCCR). Preliminary hydrostatic pressurization test revealed two leaks at the electrical feed throughs at a pressure of about 34 MPa. Replacement seals were ordered for the hydrostatic test to be witnessed by the MCCR inspector. An induction coil was made in-house for the baseline low cycle fatigue tests on economizer header material. The associated hardware for an inert gas blanket surrounding the fatigue specimen was also assembled. The planned experimentation with a different electrode to measure the electrochemical potential was delayed as no specific electrode design was selected. (Unit 4; TGD)

- Corrosion Fatigue - Crack Propagation

A literature review on environment assisted cracking showed that the major controlling factors were microstructure, stress level, water chemistry and electrochemical potential. The cracking mechanism could be very system specific. Results of on-line monitoring of economizer circuit in a thermal unit indicated that the oxygen level varied from a very high level (up to about 5 ppm) during start up to below 10 ppb under steady state conditions. Hence a static autoclave system for testing Compact Tension Specimen could examine crack growth behaviour in the worst case situation. Such an autoclave system, with provision for later conversion to a flowing system, was specified and ordered. Specifications on equipment for water chemistry control and monitoring were also prepared. (Unit 4; CEA and TGD)

- Residual Creep Life Studies

The CEA project entitled 'Residual Life of Main Steam Lines and Headers' was completed and the final report submitted. This indicated that components which operate under design conditions, eg, main steam lines, should attain a service life of 200 000 hours. However, where temperatures exceed design levels, eg, in superheater and reheater outlet headers, creep failures could occur within this time. A plant monitoring procedure to allow component life assessment was given, and recommendations for further research work to refine prediction techniques were made.

Modifications to the uniaxial creep testing facility were completed so that testing may now be carried out under constant load or constant stress conditions. Constant stress testing of normalized and tempered 2-1/4 Cr-1 Mo material is underway. Analysis of these data should provide a method of predicting the creep strain/time response of this material over times to failure up to 40 years.

A number of modifications to the tube testing facility have been initiated to increase the information available from each test. At year end, improvements in temperature and pressure monitoring have been completed. Delivery of two instrumented furnace liners is awaited to permit accurate mapping of specimen displacements. This equipment should provide results necessary to correlate uniaxial data with component behaviour. Identification of the stresses controlling deformation and failure in components should then allow improved predictions of plant life.

The accuracy of assessments of component condition based on carbide precipitates is determined in part by knowledge of the kinetics of precipitate growth. Examination of 2-1/4 Cr-1 Mo samples exposed under controlled conditions has been carried out using transmission electron microscopy and a Zeiss particle size analyzer. The information obtained provides a data base for life assessment of plant components.

Acetate replicas taken from the superheater and reheater headers of Lakeview Unit 6 have been examined to allow estimates of remaining component life. Optical examination revealed that both the 2-1/4 Cr-1 Mo parent material and weld metal were free of creep cavitation and cracking. This suggests that creep failure is not imminent. Life predictions were made by study of the precipitate size and distribution. These data suggest that variations in equivalent header temperature of ~50°C are present during service with peak temperatures of ~580°C. At this temperature, component life would be expected to be ~200 000 hours.

Installation of low NO_x burners at Nanticoke GS resulted in temperature increases as measured by thermocouples installed on boiler tubing. Samples of tubing were removed to allow assessment of plant condition. Post exposure creep testing and microstructural examination has indicated that greater than 50 000 hours further plant life would be expected. Study of the carbide precipitates suggested that equivalent operating temperatures were significantly less than the thermocouple readings. (Unit 4; TGD and CEA)

- Dissimilar Metal Weld Testing

Following the development of an analytical approach to DMW life prediction, a program of testing has been initiated. Initial results have been obtained from internal pressure tests and these indicated good agreement with predictions of damage development. The presence of axial bending or tensile stresses appears to be important in affecting the duration of DMW life. A test rig has been designed and built which will permit tests to be conducted with internal pressure and tensile end load. Testing was in progress by year end.

Structural analysis is being carried out to provide information regarding the sensitivity of rupture life to detailed differences in weldment microstructure. Identification of deleterious structures would permit refinements to be made to the life prediction model, and suggest methods of improving the life of service weldments.

Weldment carburization occurs when DMW are exposed to high temperatures. An understanding of the kinetics of the processes involved should be gained by studying the laboratory testpieces. Estimates of the operating temperature of service welds should then be possible by undertaking surface replication. (Unit 4; TGD)

- Performance of High Temperature Fasteners

The variation of microstructure observed in 12% Cr fasteners has been confirmed by examination of additional new and used studs. Two initial microstructures have been identified and these appear to have different creep properties when tested under laboratory conditions.

Testing of ex-service material has shown that room temperature impact properties and high temperature creep strength are significantly reduced compared with new material. These reductions appear to be a consequence of aging of the carbide microstructure. In extreme circumstances, rapid aging of the initial precipitate distribution has led to the formation of service cracks. Greater definition of manufacturing and heat treatment procedures appears necessary to prevent the formation of undesirable microstructures.

Examination of 1 CrMoV (Durehete 1055) studs has commenced. Optical metallography has not revealed any structural variation between new and used studs. However, reductions in Vickers Hardness, impact resistance and tensile strength have been detected in ex-service material. The reductions in properties were not sufficient to initiate service cracking in the fasteners examined.
(Unit 4; TGD)

- Boiler Tube Failure Analysis

The as planned manual (in collaboration with CTS) on boiler tube failure analysis was completed and submitted to the Canadian Electrical Association.

Of all the tube failures and waterside scales examined, no unusual type of failure or scales were observed. The failures were mainly due to overheating, poor weld design/set up, manufacture defects and corrosion fatigue. As a result of Lambton's reheater failures due to overheating in 1982, detailed examination of the 'alligator hide' surface cracking was carried out. There was no definite correlation between surface groove development and wall thinning. The OHRD residual life model produced a conservative estimate of the remaining life provided that ultrasonic measurement of tube wall thickness included compensation for the surface grooving.
(Units 1 and 4; TGD)

OTHER CORROSION STUDIES (VARIOUS PROGRAM AREAS)

Numerous short term tests were conducted or consultation provided on underground, aqueous and atmospheric corrosion problems such as:

- water heater corrosion;
- potential surveys of reinforcing steel in concrete;
- corrosion of alloys in fly ash and bottom ash leachates;
- corrosion of Bruce NGS A intake structure;
- corrosion of neutralizing sump drainpipe BHWP-B;
- corrosion of cadmium plated Pyrotex bracket, Bruce NGS B vacuum building;
- corrosion of Bruce NGS B vacuum building post tensioning tendons for the roof seal;
- cathodic protection systems design and maintenance at a number of generating and transmission stations;

- a review of the "state-of-the-art" in cathodic protection in thermal and hydraulic power stations for the CEA.

(Unit 1, various Ontario Hydro client groups and CEA)

1984 RESEARCH PROGRAMS

PROGRAM AREA - CONSERVATION & UTILIZATION

(a) Energy Substitution

- Metallurgical Applications of Plasma Arc Technology

Application of plasma arc heating technology in the metallurgical industry may lead to increased efficient use of electrical energy by replacing fossil fuels. It is planned to develop an industrial application work program in cooperation with other groups in Ontario Hydro and in industry. (Unit 1; ECUD)

PROGRAM AREA - NUCLEAR GENERATION

(a) Tritium Removal Facility

- Tritium Immobilization Process Development

During 1984, the TRF test loop will be completed and testing of the ITC carried out. The use of an automatic process control system will be investigated. (Unit 1; NGD)

- Darlington Tritium Immobilization System Construction

Scheduled activities during 1984 include ordering components, qualifying procedures, and starting the assembly of the TIS in a rented laboratory at Sheridan Park. (Unit 1; NGD)

(b) Fusion/Tritium Technology Related

- Development of Uranium Getter Beds

This development program is expected to be accomplished this year with the construction and testing of a 3 kg uranium bed. This work will assess the performance of a novel uranium bed for temporary tritium storage service and for its applicability to emergency loading scenarios. The bed's ability to hydride rapidly with the annular region under 1 atmosphere argon pressure will be tested. Heat transport to the environment during hydriding and dehydriding will be measured and compared with theory. (Unit 1; NGD and D&D)

- Tritium Applications Program

The test loop for the Tritium Applications Program has been designed and will be operational by February. This program will establish and verify the procedures necessary for transferring tritium from the Immobilization Tritium Container to tritium shipping containers. Information obtained during the test program will be applied to the design of the TAP glovebox loop. (Unit 1; D&D and CFFTP)

- Fusion Exhaust Fuel Cleanup

Three candidate gettering materials will be evaluated to determine their ability to remove active gas impurities from a stream of hydrogen. (Unit 1; CFFTP)

- Atomic Hydrogen Permeation Studies

This program, initiated in 1983, will continue throughout this year. The thrust of this work will be to establish the extent of asymmetric permeation of hydrogen through various composite membranes. (Unit 1; CFFTP)

- Canadian Fusion Program - Consulting

A number of short term studies on fuel cycle related subjects will be undertaken on behalf of the Canadian Fusion Program. (Unit 1; CFFTP)

(c) CANDU - Primary Side

- Corrosion Protection of Fuel Channels

Internal corrosion of fuel channels and resulting hydrogen pick up are two of the major factors contributing to the Pickering G16 failure. Therefore, extensive efforts will be undertaken to identify the major causes of enhanced corrosion and possible ways to control both metal wastage and hydrogen absorption. The work will be focussed in the following areas:

- modelling of corrosion process for predictive purposes;
- investigations to gain detailed understanding of the phenomenon;
- development of hydrogen pick up inhibitors for Zircaloy-2;
- development of corrosion inhibitors for Zirconium-2.5 Niobium;
- evaluation of effects of special events, such as decontamination, on corrosion.

(Unit 1; NGD)

- Hydriding of Fuel Channels

A program to investigate the importance of hydrogen ingress from the annulus gas has been started. The test cell has been designed. Construction of the test cell and assembly of the diagnostic equipment will begin in January. Pressure tube specimens will be stressed (under tension) in environments typical of the annulus gas to test the integrity of the oxide layers on the pressure tubes and to correlate hydrogen uptake with the extent of oxide cracking. (Unit 1; NGD)

- Delayed Hydride Cracking in PHT Environment

In 1984, the crack growth tests in PHT environment will be completed. Post test fractography and crack growth data evaluation will then be carried out to assess the effect of environment on crack growth behaviour. Additional tests or further investigation may then be required to support or to delineate the results.

(Unit 4; NGD)

- Effect of Oxide Formation in Cracks on
Delayed Hydrogen Cracking of Fuel Channels

The accelerated growth of oxides in dormant cracks on internal surface of fuel channels may cause their propagation. Concentration of lithium hydroxide in these cracks induces a corrosion rate up to 6 times faster than on a free surface. There are two possible effects: oxide jacking or wedging. Both effects will be further investigated in a series of autoclave tests. It is anticipated that these tests will be completed in 1984.

(Unit 1; NGD)

- Decontaminability of Primary Heat Transport System

Efforts to ascertain the governing factors which influence the decontaminability of magnetite covered surfaces will continue. Special attention will be paid to metallurgical effects. Furthermore, a program to study the decontamination process by electrochemical methods will be started. Initially, experiments will be formulated and designed to study cobalt deposition and dissolution on porous magnetite films, oxidation of various existing and potential decontamination reagents, reduction of magnetite and corrosion of iron under specific decontamination conditions. Materials and equipment to carry out the experiments will be procured.

(Units 1 and 3; NGD)

- Corrosion Testing New Decontamination Process

Corrosion testing of new decontamination process solvents for use in nuclear units will be undertaken. This testing is to assist in the choice of a reagent to ensure that it will have no adverse effects on pressure boundary materials, seals, galvanic couples, in crevices and weld areas. (Unit 1; NGD)

- Stress Corrosion Cracking of Austenitic
Alloys in High Temperature Waters

The program to determine the effect of decontamination on the long term integrity of primary side materials will continue. The testing of 304 stainless steel in high purity water is to continue through the first quarter of the year, with strain rates of 3×10^{-8} to 3×10^{-6} sec^{-1} , and test durations varied from 5 to 20% total elongation. Later in the year, Inconel 600 will be included in the test program and PWR/CANDU primary water environ-

ments and temperatures will be used. Strain rates and test durations will be similar to those employed for 304 stainless steel. The program may be extended to include the new decontamination process solvent. (Unit 3; NGD and LNL)

- Crevice/Pitting Corrosion of Incoloy 800
Moderator Heat Exchanger Tubing

Electrochemical testing of Incoloy 800 will be completed early in the year, and immersion testing will continue for most of 1984. Exposures will be to lake waters and several specific solutions at temperatures from ambient to 90°C. These tests will provide information on short to medium term behaviour of Incoloy 800 under a variety of conditions and provide the basis for the model heat exchanger test program. When the design is finalized and station approval is obtained, the model heat exchanger will be built. It is anticipated that the system will be available for installation by mid to late summer, if an early approval is received.
(Unit 3; NGD)

(d) CANDU - Secondary Side

- Steam Generator Corrosion Research

Testing of unstressed tube samples will continue with the aim of obtaining further information on pitting and crevice corrosion of Inconel 600 tubing. Constant extension rate testing (CERT) of Inconel 600 tubing will be continued. The environments and durations for pitting and CERT tests will be the same: high purity water with controlled oxygen and chloride contents. Exposure durations to 1000 hours are anticipated. Temperatures for the CERT tests will range from 250 to 300°C with strain rates in the range 10^{-8} to 10^{-6} sec⁻¹. Metallographic analysis will accompany the tests to quantify the results. (Unit 3; NGD and D&D)

- Stress Corrosion of Low Pressure Turbine Rotor Disc Steel

The second test series will be stopped by the end of the first quarter, and specimens will be examined for evidence of crack growth. New specimens will be installed at that time. This third test series is expected to run at least until year end.
(Unit 3; NGD and D&D)

- Electrochemical Technique Development

Effort will continue in the development of electrode assemblies. An attempt will be made to develop a pseudo-reference electrode which could provide a stable reference potential for long term high temperature electrochemical experiments. (Unit 3; D&D and NGD)

PROGRAM AREA - NUCLEAR WASTE DISPOSAL

(a) High Level Waste

- Advanced Container Corrosion Studies

The 1984 program will be a continuation of the 1983 program. The sulphide effects experiments at 150°C as initiated in 1983 will be completed. The exposed copper coupons will be examined and data analysis on results obtained will be carried out. Experiments on radiolysis effects on copper corrosion will proceed and will continue into 1985. (Unit 3; D&D)

PROGRAM AREA - THERMAL GENERATION

(a) Water/Steam System

- Superheater/Reheater Exfoliation

The field tests of chemical treatments developed to reduce oxide growth and its exfoliation tendency on internal boiler surfaces will continue. Some further limited laboratory tests will also be carried out to attempt to improve the beneficial effect of these treatments. (Unit 1; TGS and CEA)

- Erosion-Corrosion of Feedwater Heater Testing

The problem of feedwater heater failures caused by erosion-corrosion will be investigated in an effort to identify the operating parameters which lead to this condition. Laboratory tests combined with metallurgical investigations of failed tubes from the generating stations will be carried out. (Unit 1; TGD)

- High Temperature Crack Growth

Crack growth behaviour in specimens under plane strain and plane stress conditions will be compared, and an appropriate Fracture Mechanics parameter will be chosen for structural application. Since experimental results can only include a narrow range of plant operation modes, modelling will be attempted to predict crack growth rates for any given loading conditions. Some experimental spot checking may be necessary. Close liaison with the stress analysis group will be maintained to provide relevant material data for both parent and weld structure.

The crack growth experiment on a thick wall tube will be carried out depending on work priorities and manpower resources.
(Unit 4; TGD)

- Corrosion Fatigue - Crack Initiation

The hydrostatic proof test to meet safety requirements will be completed, and the autoclave vessel will be integrated with water chemistry control and data logging systems. Baseline tests on low cycle fatigue specimens in an inert atmosphere using induction heating will be completed. Fatigue experiments in the autoclave system will begin late in the year. Some experimentation on instrumentation to measure electrochemical potential and to detect crack initiation will be required. (Unit 4; TGD)

- Corrosion Fatigue - Crack Propagation

The autoclave system for testing 25 mm thick IT Compact Tension Specimens will be received and commissioned at the University of Toronto. Crack growth experiments on economizer header material will be carried out after the development of appropriate on-line system to measure crack length using LVDT clip gauge and to record electrochemical potential at the crack tip. (Unit 4; CEA and TGD)

- High Temperature Bolting - Rejuvenation

Monitoring of the Westinghouse CEA contract will continue and the program is expected to be completed by mid year. (Unit 4; CEA and TGD)

- Residual Creep Life Studies

High temperature uniaxial and tube burst testing on 2-1/4 Cr-1 Mo steel will be continued. It is anticipated that sufficient test data will be produced within the year to permit curve analysis and uniaxial/multiaxial correlations to be undertaken. Consideration will then be given to quantifying the effect of two shifting on component life. It is to be hoped that funding for such work may be available from CEA or EPRI.

Additional microstructural examination will be undertaken to extend the available information on 2-1/4 Cr-1 Mo. The requirement for similar studies on other low alloy steels will be investigated.

Surface replication techniques have been developed to provide information regarding the macro- and microstructure of service components non-destructively. The desirability of documenting this technique for the information of other Canadian utilities will be discussed with CEA.

Rupture testing of boiler tubing from Nanticoke GS will be completed to provide a further residual life assessment.
(Unit 4; TGD, CEA and EPRI)

- Dissimilar Metal Weld Testing

Critical tests to assess the life prediction model will be completed. It is hoped to continue discussions with EPRI regarding future funding for this type of work. (Unit 4; TGD and EPRI)

- Performance of High Temperature Fasteners

The reasons for the observed variation of initial microstructure in 12% Cr steel will be investigated. Material produced to an Ontario Hydro specification is in service in Lambton GS and laboratory studies will be carried out to estimate operating life.

The study of 1 CrMoV steel (Durehete 1055) will continue with microstructural investigations by transmission electron microscopy and high temperature creep tests. Replacement material is required for Lakeview GS, and will be supplied to an Ontario Hydro specification. Assessment of the serviceability of the material produced will be undertaken prior to service. (Unit 4; TGD)

- Boiler Tube Failure Analysis

This work will continue as required by CTS. Where unusual failures have occurred, new research projects will be formulated. (Units 1 and 4; TGD)

OTHER CORROSION STUDIES (VARIOUS PROGRAM AREAS)

A general consultation and testing service will be continued. Some examples of specific topics are as follows:

- General Underground, Aqueous and Atmospheric Corrosion

Short term tests will be conducted and consultation services will be provided as requested.

- Water Heater Corrosion

Short term tests will be conducted and consultation services will be provided as requested.

- Corrosion Surveys

Work will continue on monitoring the rate of corrosion of the Bruce NGS 'A' Intake structure, the corrosion coupons in the irradiated fuel bay at Pickering NGS 'B', and various metals in fly ash, bottom ash and granular 'A' material. Cathodic protection systems will be checked as requested.

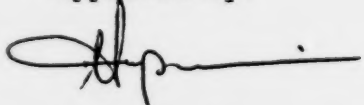
OVERVIEW

Although many of the planned work packages for 1983 (cf/1/) were undertaken, and some successfully completed, there were significant changes in priority. For example, work on crevice corrosion in pressure tubes was virtually halted and the expected annulus gas system corrosion work package was not required. Similarly, other operating problems resulted in a slight reduction in effort in the nuclear steam generation corrosion research program. As expected, research in support of the heavy water plants declined, but tritium technology related programs increased significantly with new initiatives related to the sale of tritium and in the fusion area being undertaken. Research in the thermal generation field was maintained at the minimum level to ensure current and future unit reliability and efficiency, but it should be noted that there was a marked increase in external funding in this program area.

The 1984 work program will be dominated by projects related to the Pickering NGS U2 G16 pressure tube failure. Already research is underway with respect to zirconium alloy corrosion and hydrogen absorption and migration. These projects will likely expand as the year progresses. The effect of decontamination processes (both CANDECON and any new processes) on PHT material integrity both during the cleaning and after the unit is returned to service will require an extensive effort. Moreover, a long term study to determine the mechanism of such processes using electrochemical techniques will be initiated. Therefore, the use of this latter expertise in the nuclear waste and steam generator corrosion research areas is likely to decrease to a level where we just meet our commitments to clients with little or no further work carried out.

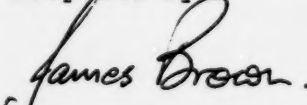
The limitations placed on our gaining new resources will necessitate no increase in work where there is actually a large demand for increased effort, eg, tritium/fusion technology. Also a new initiative in the energy utilization field (plasma arc technology) may be temporarily stalled because the required expertise is not available. Finally, work in support of thermal generation will continue with increased funding from EPRI, particularly for residual life prediction studies, likely. Current research in corrosion fatigue will be extended to nuclear systems in the medium term.

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